

PCT

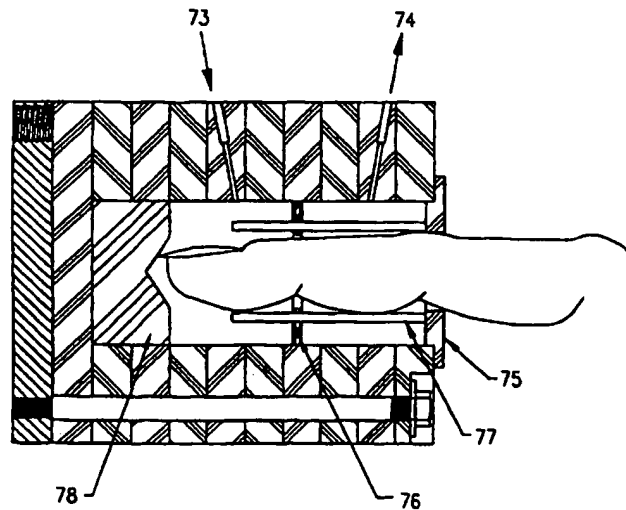
WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : <b>A61B 5/00, G01N 21/47</b>	<b>A1</b>	(11) International Publication Number: <b>WO 97/23159</b> (43) International Publication Date: 3 July 1997 (03.07.97)
(21) International Application Number: PCT/CA96/00856 (22) International Filing Date: 20 December 1996 (20.12.96) (30) Priority Data: 9526309.1 22 December 1995 (22.12.95) GB (71) Applicant (for all designated States except US): CME TELEMETRIX INC. [CA/CA]; 560 Parkside Drive, Waterloo, Ontario N2L 5Z4 (CA). (72) Inventors; and (75) Inventors/Applicants (for US only): PAWLUCZYK, Romuald [CA/CA]; 362 Roselawn Place, Waterloo, Ontario N2L 5P1 (CA). YANG, Wei [CA/CA]; 38 Beechmanor Crescent, Kitchener, Ontario N2N 3H5 (CA). HOCKLEY, Bernard, S. [CA/CA]; 5 Delma Court, Georgetown, Ontario L7G 4Z9 (CA). (74) Agent: RUDOLPH, John, R.; Gowling, Strathy & Henderson, Suite 1020, 50 Queen Street North, Kitchener, Ontario N2H 6M2 (CA).		(81) Designated States: JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  Published With international search report.

(54) Title: INTEGRATING CAVITY FOR SPECTROSCOPIC MEASUREMENT IN LIGHT SCATTERING SAMPLES



(57) Abstract

The present invention is for use in the spectroscopic field as applied to the measurement of concentrations of substances of interest in a variety of samples of uniform and non-uniform shape and composition including biological tissues and fluid samples. It incorporates the use of an integrating cavity which is capable of recovering scattered light from a given sample and re-illuminating the sample with that light thereby enhancing the potential for light absorption, which in turn, provides a stronger signal for measurement of light absorption. Samples can be as large as the interior space of the cavity, and preferably the cavity volume and shape are approximately equal to the volume and shape of the sample.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgyzstan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic	KR	Republic of Korea	SE	Sweden
CG	Congo	KZ	Kazakhstan	SG	Singapore
CH	Switzerland	LI	Liechtenstein	SI	Slovenia
CI	Côte d'Ivoire	LK	Sri Lanka	SK	Slovakia
CM	Cameroon	LR	Liberia	SN	Senegal
CN	China	LT	Lithuania	SZ	Swaziland
CS	Czechoslovakia	LU	Luxembourg	TD	Chad
CZ	Czech Republic	LV	Latvia	TG	Togo
DE	Germany	MC	Monaco	TJ	Tajikistan
DK	Denmark	MD	Republic of Moldova	TT	Trinidad and Tobago
EE	Estonia	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	UG	Uganda
FI	Finland	MN	Mongolia	US	United States of America
FR	France	MR	Mauritania	UZ	Uzbekistan
GA	Gabon			VN	Viet Nam

## INTEGRATING CAVITY FOR SPECTROSCOPIC MEASUREMENT IN LIGHT SCATTERING SAMPLES

### BACKGROUND OF INVENTION

#### 1. *Field of Invention*

The field of invention concerns the spectrophotometric determination of the concentration of substances in a light scattering sample. In particular, assessing glucose concentration  
5 in tissues of a patient by measuring the near infrared absorption by glucose *in situ* typically using a finger as the tissue sample for analysis.

#### 2. *Description of Related Art*

Measurement of the concentration of components in non-scattering samples and solutions by spectroscopic methods is a well established technique. Spectroscopic measurement  
10 usually consists of an optical instrument which generates at least one light beam whose spectral content can be controlled, analyzed and measured in the presence of a sample and can be compared with the spectral content of the same beam in the absence of sample, or other light beam, acting as a reference.

Under optimal conditions, when a detectable optical signal and its spectral content are not  
15 affected by any factors other than absorption by the sample which is introduced into a light beam from a light source, spectral variation of the detected optical signal in relation to a reference beam can provide information concerning the chemical composition of the sample. For such determinations it is critical to establish conditions which minimize extraneous factors which affect the signal. This is generally achieved by use of an optical  
20 system with a parallel test beam and by using samples in layers of pre-determined thickness. This geometry is intended to assure that the intensity of light detected by a photodetector does not depend on sample position, including small rotations or shift. In use, in circumstances where a distinguishable spectral band is generated by a particular substance's absorption of light, the information can be used to identify that substance and  
25 is particularly useful in identifying the substance in samples where the components of the sample, or target, are unknown. Relative variations in absorption spectra may be used to provide information concerning the concentration of the substance.

This technique is based on a number of assumptions. It assumes that the conditions for light propagation remain unchanged, i.e., the light beam does not change geometry. It also assumes that observed losses in light transmitted through the sample are caused only by absorption. In addition, this approach assumes that losses in detected signal depend  
5 on the thickness of the absorbing layer and the extinction coefficient (used for mathematical description of absorbance of the analyzed substance) which is proportional to the concentration of the absorber.

These assumptions do not apply in respect of strongly scattering samples or targets. For such targets, two significant factors which affect the light intensity detected by a  
10 photodetector are: 1. absorption which affects intensity of light transmitted by the sample, as just discussed, and 2. scattering of light which changes propagation conditions of light. In strongly scattering media, like the majority of biological tissues, even where absorption does not effectively occur, the amount of light which crosses the sample may be very small and its spatial distribution will differ significantly from that of an undisturbed beam. Usually  
15 this light is scattered into full solid angle. In such circumstances, the quality and quantity of detected signal greatly depends on the position of the sample in the optical instrument, being sensitive to even minor variations in position. Due to the scattering effect, a portion of the light will leave the sample without penetrating it, while the optical path of light transmitted through the sample may vary across a wide range as a result of numerous  
20 changes in direction of particular photons in the sample, all of which leads to considerable difficulty in data interpretation. Depending upon the sample and the conditions for measurement, this may result in a situation where the level of detectable light becomes very low and spectral modulation of intensity is insufficient for recognition of spectral variations of the intensity caused by absorbance by the sample. In circumstances where  
25 there is a high concentration of scattering centres (within the sample), back scatter may even prevent light from entering the sample which would result in insufficient interaction of light with the sample and a significant reduction in the amount of light which can reach the photodetector.

Consequently it follows that in the case of targets which strongly scatter light, three central  
30 problems to the measurement of characteristic absorption spectra arise:

1. how to cause stronger interaction of a source light with samples to obtain larger spectral intensity modulation;
2. how to collect more light to increase the signal; and
3. how to make the system less sensitive to sample position.

5 The present invention provides a solution to these problems by application of a light integrating cavity in a novel way. By definition, an integrated cavity is an "emptiness" with non- absorbing strongly scattering walls which scatter light in a uniform fashion. A standard integrating cavity, known as an integrating sphere, has the shape of a sphere with two or three ports depending on the application. One port is used to provide light to  
10 the cavity; the second allows light to reach some kind of photodetector (for example, it can be a spectrophotometer); and a third, optional port is provided to secure interaction of light with a target. There can be variations in respect of the cavity including, shape of the cavity, position of the light source inside or outside the cavity, position of the target and the photodetector. This kind of approach is well developed theoretically and has been well  
15 described in the literature, for example: "Theory of the Integrating Sphere" by J. A. Jacquez and H. F. Kuppenheim published in JI. Opt. Soc. Amer., 1955, Vol. 45, No. 6, pp. 460-470; or "Incomplete Integrating Sphere" by O. E. Miller and A. J. Stuart published in JI. Opt. Soc. Amer., 1958, Vol. 48, No. 11, pp. 828-831, both of which provide theoretical background to integrating spheres, which to some extent can be expanded to cavities of  
20 more general shape. Application of such generalized approaches for spectroscopic measurement is discussed in the paper: "Integrating Cavity Spectroscopy" by P. Elterman published in "Applied Optics", 1970, Vol. 9, No. 9, pp. 2140-2142. A sophisticated variant of the integrating cavity applied to spectroscopic methods is given in a paper "Integrating Cavity Absorption Meter" by E. S. Fry, G. W. Kattawar and R. M. Pope published in  
25 Applied Optics, 1992, Vol. 31, No. 12, pp. 2055-2065. The common goal of all these publications is to conduct absolute measurements of absorbance of various targets, light scattering targets in particular. In every case, in order to measure light absorbance, it is believed that the principal property of the cavity is used, i.e., to generate uniform and isotropic irradiance inside the cavity. A theoretical analysis of how a cavity achieves the  
30 results it does suggests that such conditions can be achieved only when the surface area of all holes or ports in the cavity wall are small (relative to the size of the cavity) that there is no direct coupling of light from the source to the other holes or ports. Further, if a light

absorbing target, or sample, is placed inside a cavity, its volume or extinction coefficient must be small. In other words, absorption of light by a target in a single pass must be "acceptably small". The term "small" as used here means small enough to minimally affect the uniformity of irradiance in the cavity. In addition a sample must be positioned in such a way that light from a source cannot reach it directly, otherwise, nonuniform irradiance of the target is observed, and this is contrary to the requirement of uniform illumination. Consequently, use of an integrating cavity to measure absorption by a light scattering target requires a small target and that it be placed inside a cavity in a way so as to prevent direct coupling of light from a light output hole, or source, and target. In such cases the amount of light which has interacted with the sample reaching a photodetector is very small in comparison with light which has not undergone interaction with the sample. This significantly reduces the dynamic range of the system, hence, reducing the chance of detecting such signal reduction. Dynamic range can be increased by reducing the amount of light which reaches the photodetector without interacting with the sample. Practically this may be achieved by filling the cavity with sample.

In particular, this has been achieved for liquid or gaseous samples by applying a more complex approach to obtain uniform illumination of larger samples, however such samples must be, from all aspects, of a size and shape which is commensurate with the cavity. It is possible to produce such samples in the cases of gases and liquids (which can assume the shape of the container used), and sometimes it is possible to produce solid samples of such shape and size. An ingenious way to use an integrating cavity for absorption measurement of liquids is given in the above-mentioned publication "Integrating Cavity Absorption Meter" by E. S. Fry, G. W. Kattawar and R. M. Pope. In this case, to improve uniformity of the illumination, a cavity with semitransparent diffusely scattering walls was filled with the test liquid and was placed inside another cavity. The walls of the first cavity could be considered as an additional integrating cavity, thus, in totality it could be considered as three cavities, one inside the other. The role of the external cavity is to redistribute available light around the walls of the internal cavity as far as possible. The wall of this cavity, made of strongly scattering material, could be considered as a second cavity whose role is to secure uniform illumination of the second internal cavity which contained the test liquid (it could be gas or a specially prepared solid sample which totally filled the cavity). The irradiance in each of these three cavities was tested by means of

fibre optic probes whose tips were inserted into corresponding cavities including that containing the sample, where the tip of the fibre optic sensor was in the sample (test liquid). It was shown that the relative strength of the detected signals depended on the absorption coefficient of the liquid, and, after suitable calibration this information could be used to determine the absorption coefficient of the liquid. The method assumes that irradiance distribution, at least in the internal cavity and in its walls (the second cavity) is isotropic and homogeneous. This assumption is valid only when the absorption coefficient is low. Altogether, this means that the method can only be applied for absorption measurement of weakly absorbing samples, which completely fill the internal cavity, and which will accept the tip of a fibre optic probe. It is obvious that application of this kind of method to solid targets would be very limited and it would be of little use in applications involving living creatures or parts of their anatomy which cannot be formed to the shape of the cavity and, preferably, would not accept insertion of any external probe.

Thus, while use of an integrating cavity or sphere is attractive, there is a need for some other diagnostic technique which can provide more light and will be less sensitive to position of a target and which can be used in relation to living tissues, parts of human body in particular, where neither size or shape can be changed. We have solved these problems by using an integrating cavity in an uncommon way which can be applied not only to objects like fingers but also to other targets of more complex structure.

#### BRIEF SUMMARY OF INVENTION

The present invention advances the spectrophotometric art by providing an improved means of measuring the concentration of a substance in a light scattering sample. The invention incorporates the use of an integrating cavity with multiple input and output ports which provide better illumination for cavities not completely filled with light scattering samples and consequently make a cavity less susceptible to position of the target in the cavity which is capable of recovering the scattered light from a given sample and re-illuminating the sample with that light thereby enhancing the potential for light absorption. This, in turn, provides a stronger signal and wider dynamic range for measurement of light absorption. In contrast with the prior art, surprisingly, we have found that in order to measure samples we do not require uniform small samples located in a position such that irradiation is by reflected radiation. Equally surprising is the fact that the interior surface

of the cavity need not be spherical. Further, although homogeneous isotropic illumination is preferred, it is not assumed or required in order to achieve the beneficial results from using an integrating cavity in generating absorption data. Finally, and most surprisingly, measurements of absorption by a highly light scattering sample are best where the cavity  
5 volume and shape are approximately equal to the volume and shape of the sample, as opposed to being spherical in shape.

As mentioned before, in the case of strongly scattering objects two problems arise: how to direct light for more efficient interaction with the target and how to improve its collection efficiency. A theoretical analysis of the way integrating cavities work suggests that under  
10 conditions which achieve homogeneous irradiance and distribution of light, the probability of direct coupling of light from a light entry hole to a photodetector, omitting the target, is proportional to the ratio of total volume of the cavity to volume of the target. Thus, for large cavities and small targets, the chance that light will leave the cavity without interaction with the target is very large. This chance is additionally increased if the target  
15 itself scatters light strongly. In such cases it may be that even if light reaches the target, it is back scattered to the cavity without penetration of the target and, after that, leaves the cavity without further interaction with the target. This further reduces dynamic range of the instrument and in such situations it becomes critical to increase the chance of interaction of light with the target. This is achieved applying an integrating cavity of a volume which  
20 is comparable to the volume of the sample. This increases the chance of light interacting with the target even in the case of strongly scattering samples. However, simply making the cavity of comparable volume to the sample causes the distribution of irradiance inside the cavity to become quite sensitive to the size of the target, its shape, its position in the cavity, and its relative position regarding the light input and output ports. This sensitivity  
25 is all but eliminated by application of a multiple port configuration where, instead of single large ports for the light source and photodetector, a multiplicity of smaller ports is used for illumination of the target and data collection. The ports can be distributed on the cavity's surface either in random or in some prescribed fashion depending on the cavity and target shapes. In particular, the multiplicity of ports can be localized in such way that they create  
30 some characteristic continuous pattern (a ring, for example) on the surface of the cavity. The target can be illuminated either by all entry ports simultaneously or in any spatial or temporal order. The entry ports can be powered either by a single light source, by



independent light sources for each port, or by a set of light sources, each of powering a single or any combination of ports. Any method of light division and light delivery systems (including multiple-furcated optical fibres) can be used to redistribute the light from a light source to selected ports. Light from the output ports can also be analyzed as an entity or  
5 in any selected spatial and temporal combination of ports and any method to combine light from various ports can be used. The larger the number of ports and the more uniform the distribution of entry and exit ports on the surface of the cavity, the more uniform is the cavity response to irregular targets. This system allows for multiple passes of radiation through the target and is minimally affected by scattered light and provides significant  
10 absorption signal. Consequently, the previous problems of minimal signal which are associated with measurement of absorption of strongly scattering samples, or targets, are minimized in the present invention.

In one application of this technology, namely measuring concentrations of glucose in diabetic patients, the integrating cavity overcomes many of the problems outlined above  
15 with respect to the measurement of glucose by providing a method and apparatus for measuring target substances in the blood or tissue of a patient in a non-invasive way which is not dependent on position of the tissue being analyzed yet provides a rapid accurate assessment of the concentration of the target compound. Although one type of application is described here, it is to be understood that this technology can be adapted  
20 to measure light absorption in any sample and is particularly useful in applications where the sample to be analyzed has a complex shape, and/or scatters light and/or is difficult to maintain in a immovable fixed position.

In a preferred embodiment, the invention employs the use of an integrating cavity for measurement in fingers. Although, measurement in a finger is described here, any tissue  
25 or samples would be susceptible for measurement and an integrating cavity or sphere, or other geometric shape can be employed.

In a further preferred embodiment the integrating cavity is of a convenient size which accepts the insertion of a finger into the space of the cavity with minimal space between the wall of the cavity and the exterior surface of the finger. Multiport illumination of a target  
30 and multiport detection together with integrating properties of a cavity create a uniform

response independent of shape and optical properties of a target, the directional properties of the light source and the photodetector.

5 In yet a further embodiment the integrating cavity is a tube-shaped container with multiplicity of holes, or ports penetrating the wall of the container to allow entry of a light and its collection or photo detection, this latter aspect, namely photodetection port, is preferably positioned at the bottom of the container, although any number of ports can be used to collect light, and the surface of the cavity employs a highly light reflective coating or layer.

10 In a further embodiment the ports penetrating the wall of the cavity are distributed in a random fashion.

In yet a further embodiment the ports penetrating the wall of the cavity are distributed in a characteristic continuous ring pattern.

15 In still a further embodiment the target can be illuminated by all entry ports simultaneously or in any spatial or temporal order, and the collection of light at the ports with a photodetector can be analyzed in any selected spatial and temporal combination.

In further embodiments the photodetector can be any spectrophotometer, spectrograph or spectrum analyzer, or other instrument capable of photo detection.

20 In a second type of embodiment, the invention employs the use of an integrating cavity for measurement in a stream of liquid. In this embodiment the cavity is shaped to accept a tube through which liquid will pass. The interior walls of the cavity are in contact with the walls of the tubular vessel, although contact is not necessarily required. At least one photodetector is incorporated and it is located at any selected place in the cavity. At least one light input is positioned at another location along the longitudinal dimension of the cavity. Multiple ports of entry can be used for illumination of the cavity interior.

**BRIEF DESCRIPTION OF THE DRAWINGS**

**Figure 1** is a schematic representation incorporating an apparatus of the present invention.

5 **Figure 2** is a side-view of an integrating cavity demonstrating multiple ports from the exterior to the interior of the cavity.

**Figure 3** illustrates a top-view transverse section of the integrating cavity of **Figure 2**.

**Figure 4** is a transverse section of a reconfigurable multilayer integrating cavity.

**Figure 5** is a cross-section of the reconfigurable multilayer integrating cavity of **Figure 4**.

10 **Figure 6** is a transverse section of an integrating cavity for measurements in a stream of liquid.

**Figure 7** is a cross-section of a reconfigurable integrating cavity with baffle and insert for sample positioning.

**DESCRIPTION OF THE PREFERRED EMBODIMENT(S)**

Referring to the figures, **Figure 1**, is a schematic representation of an apparatus 2 in accordance with the present invention. In **Figure 1** there is depicted a radiation emitting source 4. Radiation from the source is transmitted via fibre-optic bundles 6 to irradiate the interior of an integrating unit 8. The integrating unit can be an integrating cavity or sphere or similar device capable of receiving illumination and causing a high degree of reflection of the radiation within the interior of the unit. Fibre-optic bundles 10 received radiation from the interior of the integrating unit and transmit it to a detector 12. The detector can be a spectrograph when radiation source 4 is a broad band light source or, alternatively a photodetector when radiation source 4 is a monochromatic or a tunable laser. The photodetector integrates the optical radiation over a specified time and converts the optical signal to a time multiplexed analog electronic signal called a scan where absorbance is calculated. The electronic signal is amplified by analog electronic amplifiers and converted to a digital signal by an analog-to-digital converter or ADC. The digital information from the converter is interpreted for data analysis by a microprocessor or MP, or other appropriate processor which is in turn connected to a computer. The results of the data analysis can be shown on an output device such as a display and on a printer. A user can control the device to specify a particular interferent to be analyzed and to determine the number and timing of measurements.

- Referring next to **Figure 2**, an example of the integrating unit 2 of **Figure 1** is depicted. Namely, this integrating unit is an integrating cavity 14 with eight (8) (six ports 16, 18, 20) ports that communicate from the exterior to the interior of the cavity. In **Figure 2**, three input ports 16 are illustrated longitudinally linearly located on a first side of cavity 14.
- 5 **Figure 3** which provides a different view of cavity 14, illustrates a further three entry ports 16 located opposite the three entry ports 16 referred to above in respect of **Figure 2**. Ports 16 are multiple input ports which accept fibre-optic bundles from the radiation source and thereby provide illumination to the interior of the cavity. A port 18 at one end of the cavity is of sufficient circumference to allow insertion of a digit or other target while a port
- 10 20 positioned opposite entry port 18 is where fibre-optic bundles receive radiation and transport it to a detector 12. Optionally, the detector can be positioned at the port. Further, while six (6) entry ports and one (1) exit, or detector port are shown, the number of ports can be increased or decreased (to a minimum of one of each) depending upon the circumstances.
- 15 The surface of the cavity 22 is made of a material capable of efficient back scattering of illumination such as Spectralon™ or other such material and may be a coating or a layer of such material. The cavity may contain a support 21 for positioning of the tip of a finger within the cavity (there may be more than one and it may appear differently depending on the target). The support is made of, or covered with a material capable of efficient back
- 20 scattering of illumination such as Spectralon™ or other such material.

- Figure 4** provides an illustration of another example of integrating unit 8. This unit is an integrating reconfigurable cavity comprised of a multiple "ring" 32 assembly with variable numbers of input ports 34 that communicate from the exterior to the interior of the cavity for entry of input fibres at various directions. The port for entry of a digit is 38 and the
- 25 output port is 40. The embodiment illustrated in **Figure 4** consists of 12 "rings" which are held together by a locking pin 42, and in this embodiment there are three such pins. Counting from port 34, the number of input ports, beginning with ring number 3, is 19, followed by a ring with no input ports, which is followed by a ring with 5 input ports followed by a ring with no input ports, which is followed by a ring with 19 input ports, followed by a

ring with no input ports, which is followed by a ring with 5 input ports, which is followed by a ring with no input ports which is followed by a ring with 19 input ports, and this is followed by a ring with no input ports, which is followed by a base 44 which contains an exit port 40. The base is removably fixed to an external base 46 which also contains an exit port 40, and in which the locking pins are fixed. It is to be understood that the number of rings, the number of entry ports and the number of exit ports as well as their relative positions on the cavity, can all be varied, so long as there is at least one port for the sample to enter, one port for light entry and one port for light to exit.

The rings are made of a material capable of efficient back scattering of illumination such as Spectralon™ or other such material, or the interior of each ring may be covered with a coating or a layer of such material. Figure 5 provides a cross sectional view and illustrates the three locking pin sites 42, as well as the exterior to interior input ports 34. While ring-shaped layers are described here, it is understood that any other shape can be used.

Referring to Figure 6 a further embodiment of the integrating cavity is shown. This embodiment is intended for use in measuring the concentration of substances in a fluid which is flowing through the interior of the cavity. The integrating cavity 60 optionally contains a tube 62 through which the sample fluid 63 flows. The cavity may be constructed of layers as is the cavity illustrated in Figure 4, or it may be, and is preferably of unitary construction as is the cavity illustrated in Figures 2 and 3. The walls of the cavity 64 are made of a material capable of efficient back scattering of illumination such as Spectralon™ or other such material, or the interior of the cavity may be covered with a coating or a layer of such material. The radiation source 66 is optically connected to the cavity by fibre optic cables 68 preferably at both ends of the cavity however, input ports can be varied in respect of number of input ports and location along the length of the cavity. A photodetector 70 is optically connected to the cavity by fibre optic cables 72 preferably at the centre of the cavity however, output ports can be varied in respect of number of output ports and location along the length of the cavity. In addition, the input source may be located at the input ports as can the photodetector be located at the output ports.

**Figure 7** presents a cross-section of a reconfigurable integrating cavity which has been specifically adapted for a finger sample to be positioned within the cavity. The cavity illustrated has multiple input and output ports respectively (**73** and **74**) and special features to allow immobilization of a finger in position and to reduce light "leak-out" when finger diameter is significantly less than the diameter of the cavity. Collar **75** is made of Spectralon™, or other such material, and assists in preventing light leakage from the cavity. Baffle **76** is also made of Spectralon™ or other such material, and assists in preventing direct light coupling between input and output ports (**73** and **74** respectively) as well as assisting in holding the finger in position within the cavity. Movement of the finger sample is further prevented by leading rods **77** while the finger tip is positioned in a conical recess at the bottom of the cavity **78**. As is evident and as would be understood by those skilled in the art the sample effect can be achieved with a cavity made from a single piece of light scattering materials or other highly reflecting materials. It should also be understood that any other means which assists in immobilizing the sample for the purposes of measurement are within the scope of the present invention.

While an apparatus which is capable of measuring the concentration of target substances in the blood or tissue of a patient in a non-invasive way which is not dependent on position of the tissue being analyzed yet provides a rapid accurate assessment of the concentration of the target compound is described here, it is to be understood that this technology can be adapted to provide embodiments that measure light absorption in any sample and is particularly useful in applications where the sample to be analyzed has a complex shape, and/or scatters light and/or is difficult to maintain in a immovable fixed position. It may also be adapted to measure the concentration of target substances in a flowing sample of fluid.

It is understood that this disclosure relates to a method of measuring the concentration of target substances in the blood or tissue of a patient in a non-invasive way which is not dependent on position of the tissue being analyzed and providing a rapid accurate assessment of the concentration of the target compound. It is further to be understood that this methodology can be adapted to measure light absorption in any sample and is particularly useful in applications where the sample to be analyzed has a complex shape, and/or scatters light and/or is difficult to maintain in a immovable fixed position. It may

also be adapted to measure the concentration of target substances in a flowing sample of fluid.

While the invention has been particularly shown and described with reference to certain embodiments, it will be understood by those skilled in the art that various other changes  
5 in form and detail may be made without departing from the spirit and scope of the invention.

## WE CLAIM:

1. An apparatus for measurement of a concentration of at least one known substance in a non-uniform sample, said apparatus comprising:
  - 5 a. an integrating cavity having an interior and exterior wherein said sample is placed in the interior, said integrating cavity having at least two ports extending from said exterior to said interior;
  - b. a radiation source for emitting a beam of radiation;
  - c. means for transmitting said beam of radiation to the interior of said cavity;
  - d. means for receiving radiation from said interior of said integrating cavity;
  - 10 e. a sensor optically connected to said interior of said integrating cavity wherein said sensor is responsive to receipt of radiation from said interior of said integrating cavity;
  - f. means for correlating a sensor response from said sensor to a quantity of at least one known substance in said sample.
- 15 2. The apparatus of claim 1 wherein said integrating cavity contains a multiplicity of input and out put ports.
3. The apparatus of claim 1 wherein said integrating cavity is cylindrical in shape with an open end and a closed end.
4. The apparatus of claim 3 wherein said integrating cavity is reconfigurable.
- 20 5. The apparatus of claim 1 wherein said interior of said integrating cavity is made of a material capable of efficient back scattering of illumination.
6. The apparatus of claim 5 wherein said material capable of efficient back scattering of illumination is Spectralon.



7. An apparatus for the measurement of a concentration of at least one known substance in a human digit, said apparatus comprising:

- 5 a. a reconfigurable cylindrical integrating cavity having an open end, a closed end, an interior consisting of Spectralon, an exterior, a collar consisting of Spectralon to partially cover said open end and allowing entry of said digit to the interior of said cavity, a baffle having a perimeter in contact with the interior walls of said cavity and capable of encircling said digit in said cavity, and leading rods to help hold said digit in fixed position in said cavity, and multiple output ports located above said baffle, and multiple input ports  
10 located below said baffle;
- b. a spectrophotometer optically coupled to said input and output ports to provide a source radiation and to measure absorbance of radiation by said digit; and
- 15 c. means for correlating said measured absorbance to a quantity of said at least one known substance in said digit.

8. A method for measurement of concentration of at least one known substance in a non-uniform sample, said method consisting of the following steps:

- 20 a. placing said sample into an integrating cavity having an interior and exterior wherein, said integrating cavity has at least two ports extending from said exterior to said interior;
- b. providing a radiation source for emitting a beam of radiation;
- c. providing a means for transmitting said beam of radiation to the interior of said cavity;
- 25 d. providing a means for receiving radiation from said interior of said integrating cavity;
- e. providing a sensor optically connected to said interior of said integrating cavity wherein said sensor is responsive to receipt of radiation from said interior of said integrating cavity;

- 16 -

- f. correlating a sensor response from said sensor to a quantity of said at least one known substance in said sample.
9. The method of claim 8 wherein said integrating cavity contains a multiplicity of input and out put ports.
- 5 10. The method of claim 8 wherein said integrating cavity is cylindrical in shape with an open end and a closed end.
11. The apparatus of claim 10 wherein said integrating cavity is reconfigurable.
12. The apparatus of claim 8 wherein said interior of said integrating cavity is made of a material capable of efficient back scattering of illumination.
- 10 13. The apparatus of claim 12 wherein said material capable of efficient back scattering of illumination is Spectralon.
14. A method for the measurement of a concentration of at least one known substance in a human digit, said method consisting of the following steps:
- 15 a. placing a digit into a reconfigurable cylindrical integrating cavity having an open end, a closed end, an interior consisting of Spectralon, an exterior, a collar consisting of Spectralon to partially cover said open end and allowing entry of said digit to the interior of said cavity, a baffle having a perimeter in contact with the interior walls of said cavity and capable of encircling said digit in said cavity, and leading rods to help hold said digit in
- 20 fixed position in said cavity, and multiple output ports located above said baffle, and multiple input ports located below said baffle;
- b. providing a spectrophotometer optically coupled to said input and output ports to provide a source radiation and to measure absorbance of radiation by said digit; and

- c. correlating said measured absorbance to a quantity of said at least one known substance in said digit.

15. The use of a spectrophotometric apparatus incorporating an integrating cavity to measure a concentration of at least one known substance in a non-uniform sample.

- 5 16. The use of claim 15 wherein said sample is a human digit and said integrating cavity is a reconfigurable cylindrical integrating cavity having an open end, a closed end, an interior consisting of Spectralon, an exterior, a collar consisting of Spectralon to partially cover said open end and allowing entry of said digit to the interior of said cavity, a baffle having a perimeter in contact with the interior walls of said cavity and capable of  
10 encircling said digit in said cavity, and leading rods to help hold said digit in fixed position in said cavity, and multiple output ports located above said baffle, and multiple input ports located below said baffle.

17. The apparatus of claims 1 and 7 wherein one of said at least one known substance is glucose.

- 15 18. The method of claim 8 and 14 wherein one of said at least one known substance is glucose.

19. The use of claims 15 and 16 wherein one of said at least one known substance is glucose.

1/5

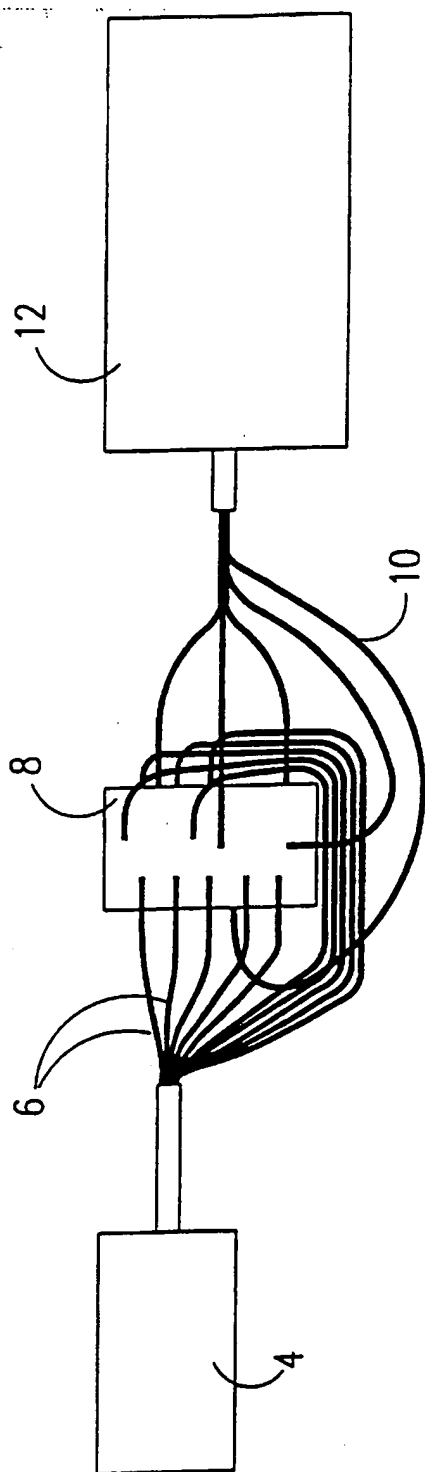
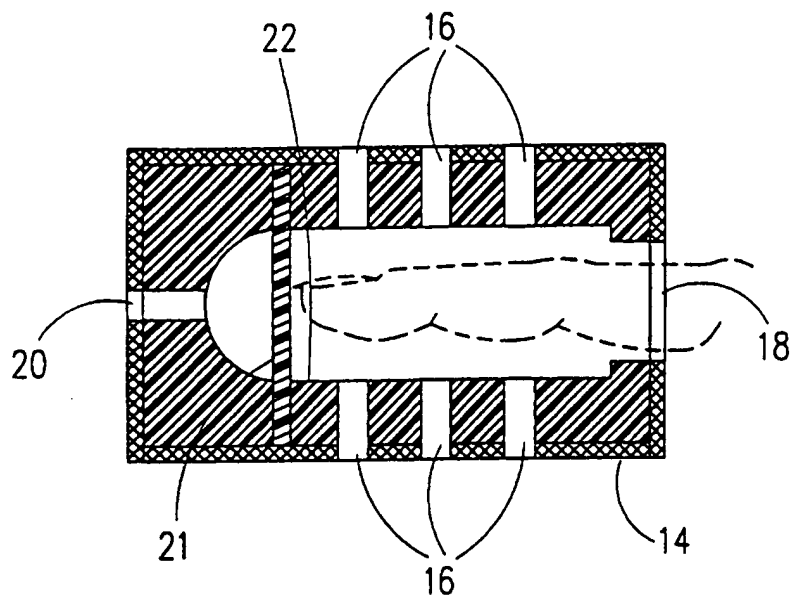
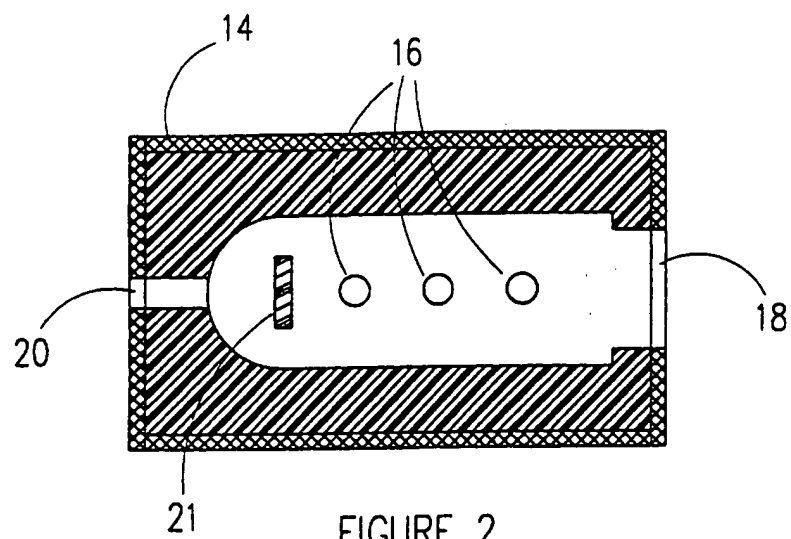


FIGURE 1

2/5



3/5

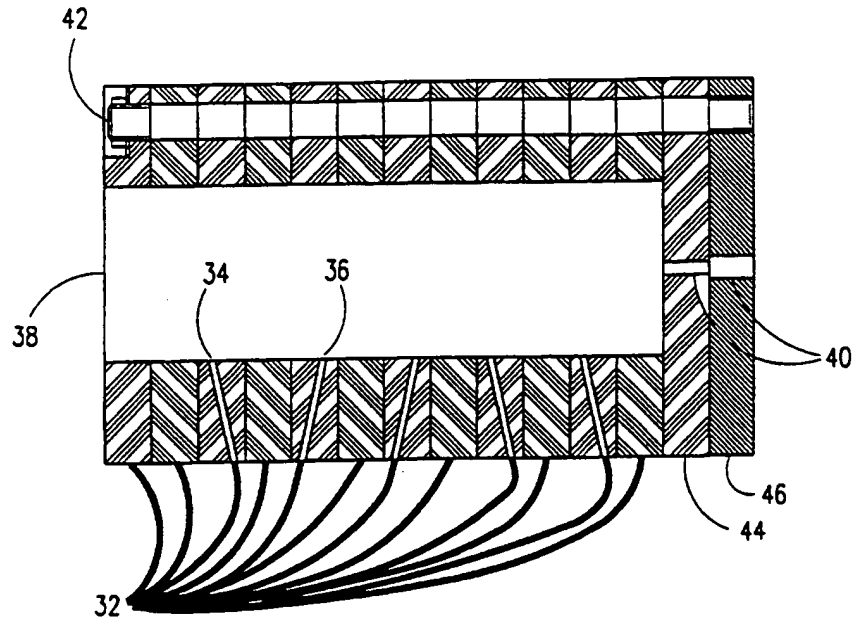


FIGURE 4

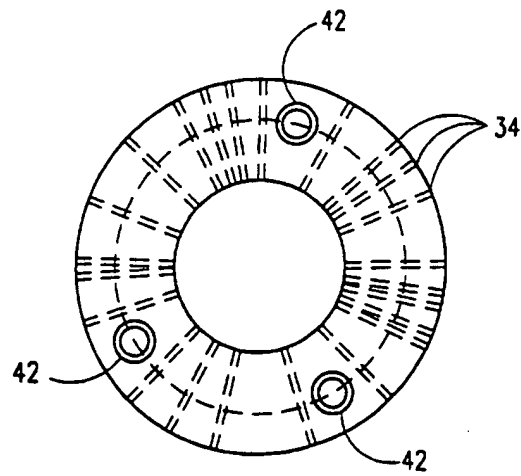


FIGURE 5

4/5

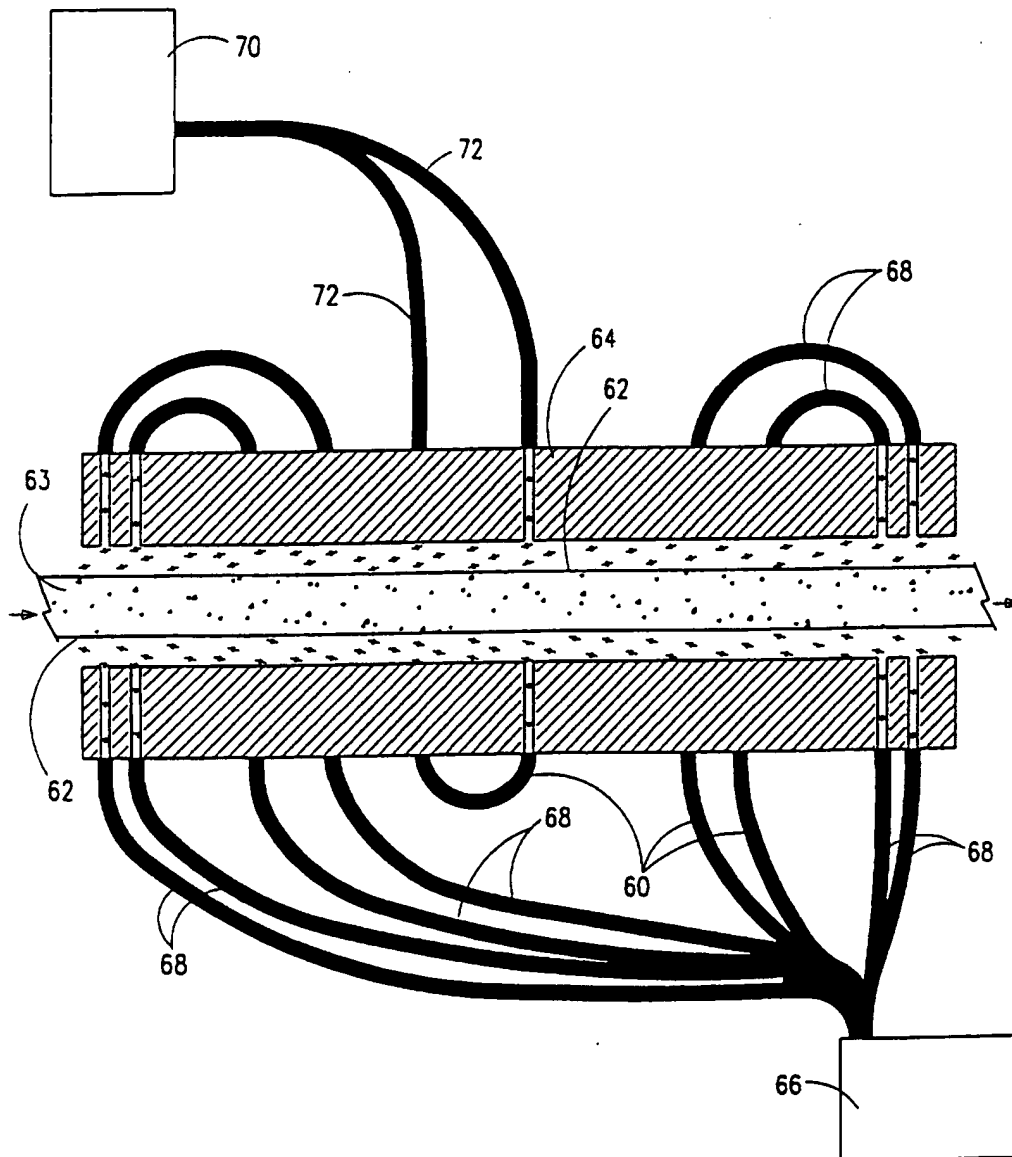


FIGURE 6

5/5

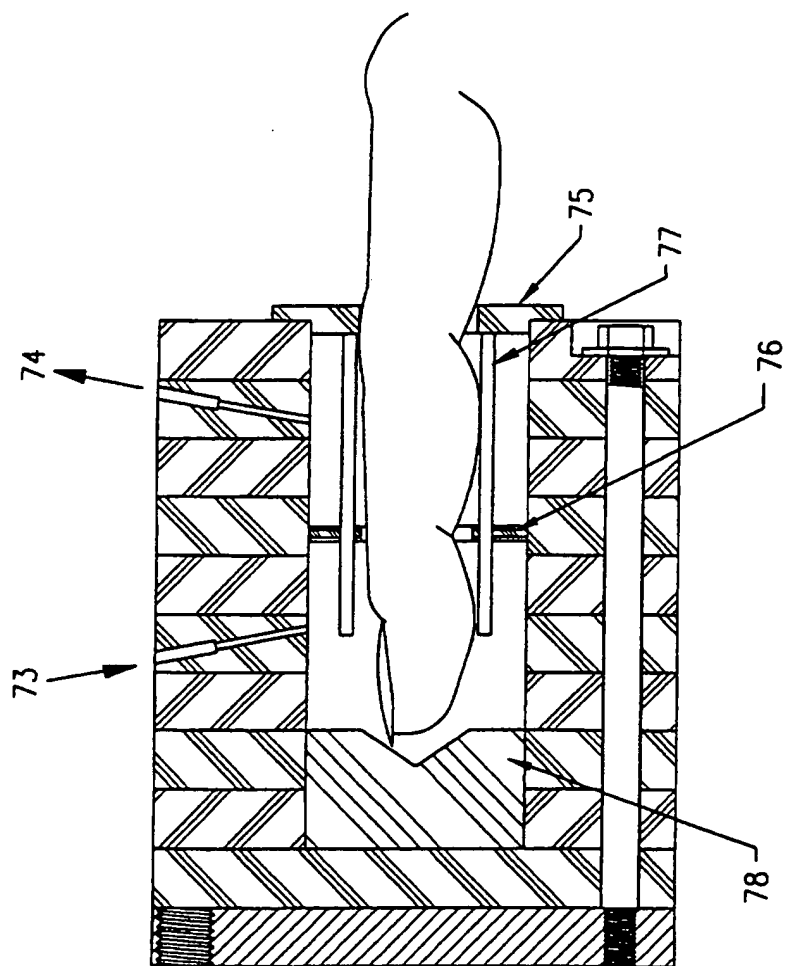


FIGURE 7



# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/CA 96/00856

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC 6 A61B5/00 G01N21/47		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) IPC 6 A61B G01N		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used)		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 768 390 A (BAKER NEIL R ET AL) 6 September 1988	1,2,4-6, 8,9, 11-13
A	see column 2, line 55 - line 61  see column 4, line 67 - column 5, line 54; figures	7,10,14, 15
X	WO 94 16615 A (NIM INC) 4 August 1994	1,4,5,8, 11,12
A	see page 4, line 26 - line 28 see page 7, line 29 - page 8, line 35; figures 2,2A,2B	3,7,14, 15,17-19
X	US 4 867 559 A (BACH DAVID T) 19 September 1989	1,4-6,8, 11-13
A	see column 5, line 36 - column 6, line 15; figure 1	7,14
-/-		
<input checked="" type="checkbox"/> Further documents are listed in the continuation of box C. <input checked="" type="checkbox"/> Patent family members are listed in annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "A" document member of the same patent family		
Date of the actual completion of the international search  2 April 1997		Date of mailing of the international search report  09. 04. 97
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016		Authorized officer  Scheu, M

# INTERNATIONAL SEARCH REPORT

Internat. J. Application No.  
PCT/CA 96/00856

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 372 136 A (STEUER ROBERT R ET AL) 13 December 1994 see figures 1,1A -----	3,7,10, 14

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/CA 96/00856

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4768390 A	06-09-88	AU 576301 B AU 5997686 A CA 1266997 A DE 3684054 A EP 0209247 A WO 8607461 A JP 62503126 T	18-08-88 07-01-87 27-03-90 09-04-92 21-01-87 18-12-86 10-12-87
WO 9416615 A	04-08-94	US 5402778 A CA 2154062 A CN 1116819 A EP 0682495 A JP 8509287 T US 5596987 A	04-04-95 04-08-94 14-02-96 22-11-95 01-10-96 28-01-97
US 4867559 A	19-09-89	NONE	
US 5372136 A	13-12-94	US 5351686 A US 5456253 A US 5499627 A	04-10-94 10-10-95 19-03-96